DESIGN AND DEVELOPMENT OF INTERACTIVE SYSTEMS FOR INTEGRATION OF COMPARATIVE VISUAL ANALYTICS IN DESIGN WORKFLOW

MARYAM ZAREI[1], HALIL ERHAN[2], AHMED M. ABUZURAIQ[3], OSAMA ALSALMAN[4] and ALYSSA HAAS[5]
[1,2,3,4]*Simon Fraser University*
[1,2,3,4]*{mzarei|herhan|aabuzura|oalsalma}@sfu.ca*
[5]*Stantec*
[5]*alyssa.haas@stantec.com*

Abstract. In architectural design, data-driven processes are increasingly utilized in creating and selecting design alternatives. Multiple design-aid systems that support such processes exist. Still, these systems dominantly support parametric modelling only or lack sufficient support for organizing, scanning and comparing multiple alternatives in the process of their creation while considering both their forms and performance data. In this paper, we argue that (a) evaluating and selecting potential alternatives must take place in the same context they are created and explored, (b) interactive data visualizations can provide real-time feedback about various aspects of design alternatives, and they should be incorporated as early in the design process as possible, and (c) design environment must enable comparing design alternatives as an integral part of the design workflow. We call our approach “comparative design analytics,” which aims to identify, develop, and validate practical key features of visualization tools for assisting designers in analyzing and comparing multiple solutions with their data. We present D-CAT as a visualization prototype tool integrated with an existing CAD application. D-CAT acts as a platform for generating knowledge about using interactive data visualization for comparing design alternatives. Our goal is to transfer the findings from evaluating this interface to developing practical applications for real-world use.

Keywords. Comparative Design Analytics; Interactive System Development; Design Data Visualization; Design Workflow Augmentation; Creativity Support Tool.

1. Introduction

In architectural design, data-driven decision-making is gaining momentum(Kasik et al., 2005; Bilal et al., 2016). Considering design performance has become instrumental in generating and selecting design alternatives. We observe a general shift towards balancing the concerns of building form and performance as early as

PROJECTIONS, Proceedings of the 26th International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA) 2021, Volume 2, 121-130.

possible and throughout the design life cycle (Shi, 2010; Deutsch,2015; Erhan et al., 2020). Designers can use data to assess the degree to which they are fulfilling their project's objectives. (Inyim et al., 2015).

Although multiple systems have been proposed for working with design data (Doraiswamy et al., 2015; Wang and Steenblik, 2019; Parametric Monkey,2020; Ramboll Computational Design, 2020), we have yet to see a robust and seamless interaction between design form exploration and performance analysis. The specialized tools for this purpose either have a 'high threshold' for use in the early phases (Shneiderman et al., 2006a) or are computationally expensive to be used in a process parallel to design. Besides, most such systems rely on parametrically defined models, which are less efficient for early idea exploration. These interfaces also lack features necessary for organizing, scanning, and comparing alternatives considering their projected performances (Woodbury,2017; Garg and Erhan, 2019). Furthermore, data visualizations are generally overlooked or miss form-data dependence (Hamilton and Watkins, 2008; Bilal et al., 2016; Thelin et al., 2019). For design data analysis tasks, designers usually resort to general-purpose or improvised data analytics tools (Vergara,2018; Bilal et al., 2016), which force the evaluation and comparison of design alternatives to be relatively separated from (rather than integrated with) the design process.

Working with alternative solutions is a recurring and established pattern in design; we argue that (a) evaluating and selecting potential alternatives must take place in the same tool-ecosystem in which they are created;(b) decision-making must be supported by customizable interactive data visualizations that can reveal performance and form aspects of each alternative;(c) comparing design alternatives must be an integral part of the design process.

We put these arguments‘ plausibility to test on a prototype system composed of design data visualizations and interfaces that we have been developing with our industry partners as part of our 'design analytics‘ research program. We call the prototype Design Comparative-Analytics Tool, in short D-CAT. Its primary use case focuses on analyzing and comparing multiple directly-modelled design models seamlessly in the same design environment. Unlike single-state models and aligned with the discussions by Terry and Mynatt (2002); Woodbury(2017), D-CAT supports working with and comparing multiple alternatives with their form and performance data in the process and context of creating them. To achieve this, D-CAT extends FlowUI developed by Erhan et al.(2020).FlowUI can analyze non-parametric design models represented as manifold solid geometries with custom attributes and compute their select performance data in early design phases. FlowUI also presents computed data in real-time on a form-data visualization dashboard for design analytics. D-CAT extends these interfaces to include visualizations for comparing alternatives in real-time or on-demand, and without leaving the modelling environment. This approach aims to expand the designers' search space without the constraints of labour-intensive parametric modelling (Davis, 2020).

2. Background

The literature on design data analysis reveals opportunities and concerns on how the design data is accessed and used for decision making. We emphasize two of these concerns: the mismatch between the tool and the tasks in using design data and the limitation of the modelling techniques such as parametric or directly-interactive modelling for rapid feedback in design-decision making.

Design decisions rely on the analysis of design data (Danhaive and Mueller,2015; Touloupaki and Theodosiou, 2017). However, in general, taking advantage of these tools requires setting up parametric design models or using tools parallel to modelling systems (Fu, 2018). Frequently used simulation programs such as EnergyPlus (Crawley et al., 2001) and Ecotect (Roberts and Marsh, 2001)require design models to be restructured to their required computational format. In these tools, the process of modelling, analyzing, and decision making is discrete, and several steps of modifications and data transfer between tools are needed to achieve the desired outcome (Shi, 2010; Erhan et al., 2020). On the other hand, directly-modelled design models are preferred for their agility and the low-effort required for their setup (Hanna, 2012; Megahed, 2015; Erhan et al., 2020).

Direct modelling tools offer limited support for evaluating the performance of the modelled alternatives (Weytjens et al., 2012; Soebarto et al., 2015). The evaluation is implicit and only left to the designers' interpretation(Zapata-Lancaster and Tweed, 2016; Erhan et al., 2020). To address this issue, multiple parallel tools are proposed (Doraiswamy et al., 2015; Wangand Steenblik, 2019; Parametric Monkey, 2020; Ramboll Computational Design,2020; Erhan et al., 2020). A major bottleneck of these tools is that they continue to support single-state documents, i.e. they only allow working with one design option at a time. This limitation hinders designers from comparing the alternatives they are exploring, for example, to identify their respective potentials or drawbacks.

3. Developing D-CAT: Methods

In this research, we adapted the design study approach as a problem-driven research method. It involves "analysis of a specific real-world problem faced by domain experts, designing a visualization system that supports solving this problem, validating the design, and reflecting about lessons learned in order to refine visualization design guidelines." (Sedlmair et al., 2012, p.2). We developed and used D-CAT prototypes to generate knowledge about how design alternatives can be compared with each other using their associated form and performance data as an integral part of design exploration using interactive design analytics visualizations. The D-CAT visualizations are developed in collaboration with our industry partner, and we have evaluated them incrementally and continuously with domain experts. Below, we summarize the initial high-level requirements for D-CAT, which are derived from a literature review, design research, and our discussion with experts from the industry:

- **RQ1.** Support the comparison of design options by visualizing both form and performance data in real-time or on-demand and in the same context they are created.

- **RQ2.** Enable customization of visualization of concerns, e.g. including or excluding data, selecting visualizations, toggling performance parameters on or off to compare, ordering design options, etc.
- **RQ3.** Allow exploration in the modelling tool while keeping visualizations on the locus of attention.
- **RQ4.** Provide support for storing, retrieving and sharing multi-state design form and data in the modelling systems.

For system development, along with the design study method, we combined the use-case driven and agile software development process (Beck et al., 2001)with design-develop-evaluate cycles. This process is initiated by identifying a set of priority use cases related to selecting and visualizing design data with domain experts, inspecting alternatives on data visualizations, and developing a workflow for comparing form and data. The project includes a demonstration of FlowUI and D-CAT as a design analytics platform for decision-making and assessing its role in the design. We will perform a formative qualitative system-evaluation through expert review in the next phase (Creswell and Poth,2016; Tory and Moller, 2005), which has been delayed due to COVID-19 restrictions.

D-CAT is a form of Creativity Support Tools (CST) (Shneiderman et al., 2006a) that provides rich interactions for exploration and comparison tasks. D-CAT's features are designed to augment creative decision making by presenting design form and data in a flexible structure. In current practice, general-purpose data visualization tools are used for studying design-data. However, they are cumbersome to integrate into the design decision-making, which is a fast, delicate, and cognitively intense process. The interrupted information flow between the parallel tools hinders real-time updates retrieved from the modelling environment (RQ4). To address this external and parallel tools' problem, D-CAT is coupled with the modelling environment, and it separates the design tasks from the management of design data.

We use HumanUI (Heumann, 2020) in experimenting with the interface designs (Figure 1). The advantage of HumanUI is that it is available as an extension to a widely used modelling environment, Rhino (McNeel, 1998), and takes advantage of CAD's internal model representations. It is a cost-effective alternative for rapid prototyping with its low-threshold for rapid development of prototype interfaces (Shneiderman et al., 2006b). Although it is limited for low-level interface programming, it provides an ecologically valid setting as designers and software developers use it in design practice for early prototype development.

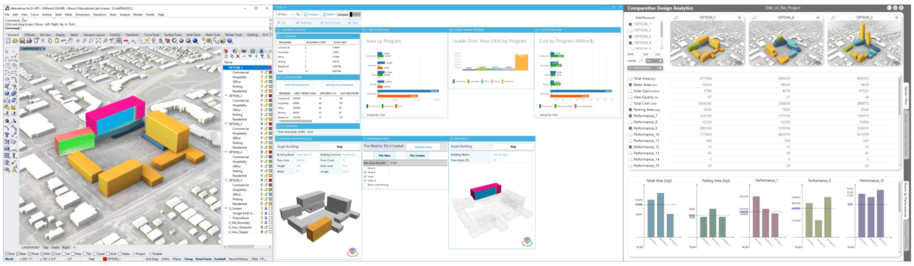

Figure 1. Left: Rhino modelling environment (McNeel, 1998). Middle: FlowUI interface (Erhan et al., 2020). Right: D-CAT interface. The three windows are integrated as our requirements (RQ4) suggest.

4. D-CAT System Design

To address the high-level requirements we listed above and building on previous research by Erhan et al. (2020), we developed a system architecture for D-CAT (Figure 2). This architecture allows interactive form exploration in the CADtools while presenting form and performance data on interactive visualizations (Gleicher et al., 2011) (RQ4) (Figure 1).

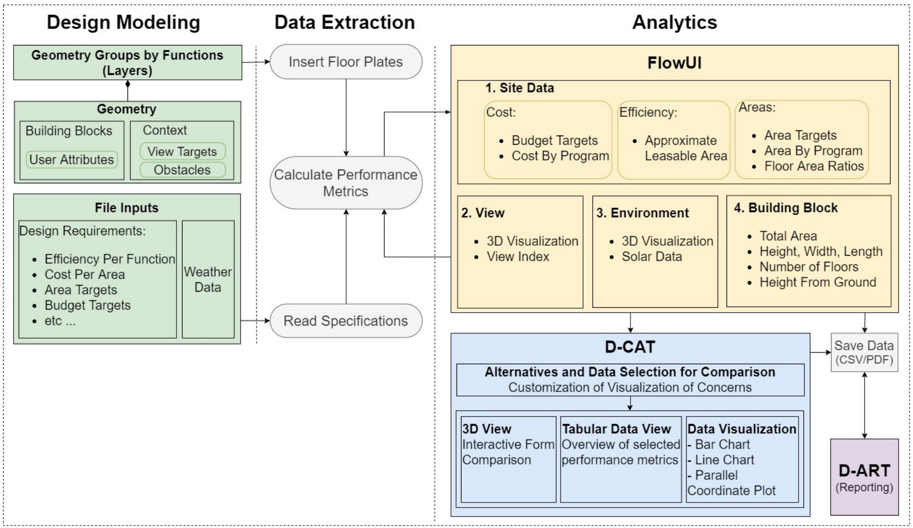

Figure 2. FlowUI—D-CAT System Architecture.

The D-CAT is part of a modular system architecture. Its primary function is to receive design data from an analytics module (e.g. FlowUI) for each alternative. D-CAT retrieves and visualizes design data as synchronized 3D form views, interactive queries on tables or charts, and customizable panels (Figure3). However, it cannot change design models in its current implementation: the information flow is unidirectional due to the technical difficulty we have faced in the system's API, which we will address in the next phases.

5. D-CAT Interfaces and Visualizations

D-CAT's interface facilitates diverse comparison tasks such as juxtaposed visualization of forms, selective comparison of performance metrics, grouped-by-alternatives or grouped-by-metrics comparisons, etc. All of which can be performed in real-time or on-demand (Figure 4). The interface consists of four main interaction panels (Figure 3): 1. Alternatives and PerformanceData Selection (RQ1 and RQ3); 2. Interactive 3D Geometry Visualization(RQ2); 3. Performance Metrics Tabular View (RQ2); and 4. Performance Data Visualizations (RQ2).

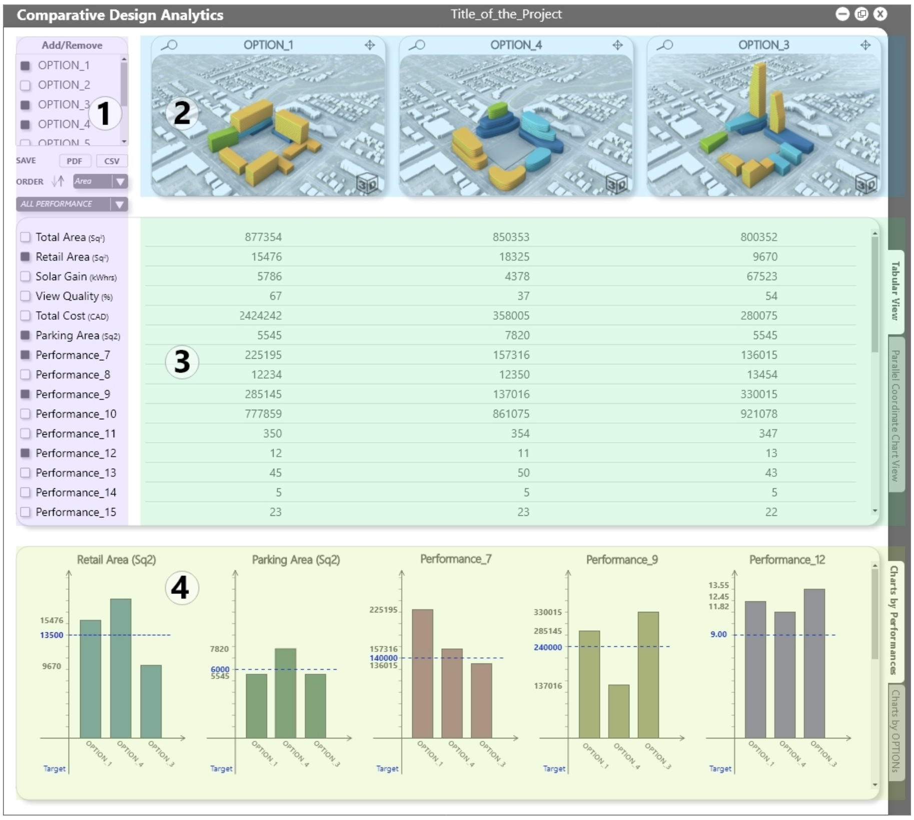

Figure 3. The four panels on the D-CAT interface.

The Alternatives and Performance Data panel provides customizable visualization of design data (Figure 4[1]) following the selection of design options. The system can export the comparison data to be shared with others or be further analyzed in design navigation tools such as DesignExplorer (Thornton Tomasetti CORE Studio, 2020) or DesignSense (Abu Zuraiq, 2020) in a parallel process.

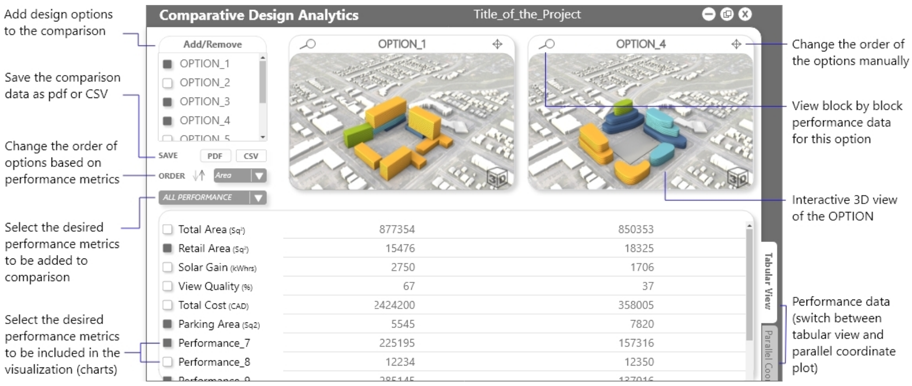

Figure 4. Possible interactions in the D-CAT interface based on the high-level requirements identified for a comparative design analysis system.

Juxtaposed design models are presented in the 3D Visualization panel. We use a colour-coded 3D form view, e.g., to indicate the associated functions of the building blocks (Figure 4 [2]). The Tabular Data View provides an overview of the selected performance metrics in a list with selectable data items [3]. The bottom panel (Figure 4, [4]) is composed of customizable visualizations such as bar charts, parallel coordinates plot, line chart, etc. (Figure 5).

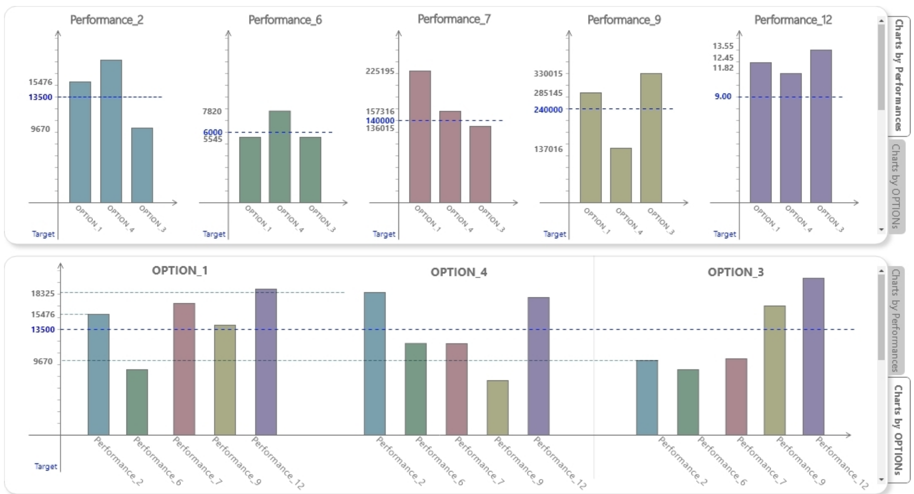

Figure 5. Top: Bar charts combining design options; Bottom: Bar charts showing the select performance metrics for each option.

6. Discussion and Conclusions: Thoughts on Comparative Design Analytics

This paper mainly argues a mismatch between the tasks and tools for working with multiple design alternatives, especially for comparison tasks considering alternatives forms and performance data. This mismatch creates a significant bottleneck in the design workflow. Hence, we should focus on searching for a new set of tools specifically designed to augment designers' capabilities for exploring multiple alternatives informed by data as early as possible in the design workflow. These tools should be developed and tested to replace the improvised and often scattered generic tools. D-CAT is an attempt towards achieving this goal. Although in its early stage, we plan to use it as a platform for learning more about the tasks and tool features required to streamline the exploration, comparison, and improvements of design alternatives.

We have identified the high-level requirements for such systems. The validation of these requirements will need further testing of D-CATvisualizations with designers working on real-world cases. We emphasize that the identified shortcomings of D-CAT interfaces are not necessarily reflections of the ideas behind them but most likely the design-choices we made in their implementation (Sedlmair et al., 2012). Therefore, we will continue developing different D-CAT versions to gradually generate knowledge around how such systems improve design-decision making. The iterative cycles of develop-test-reflect, which we adopted as part of the design study methodology, is proven to be effective in other domains relying on new interactive visualization solutions. Evaluation of design data visualization systems has two aspects to consider: the interface design decisions and the novel tasks proposed through these interfaces (Lam et al., 2012). In the next phase, we will conduct an expert review (Tory and Moller, 2005) as a formative evaluation of D-CAT with respect to predefined criteria on both the tasks and the visualizations supporting these tasks. This review is expected to reveal the concerns to be addressed in the following iterations as future work. We also plan to test the functional features of D-CAT in practice in collaboration with our industry partners.

References

Beck, K., Beedle, M., Van Bennekum, A., Cockburn, A., Cunningham, W., Fowler, M., Grenning, J., Highsmith, J., Hunt, A., Jeffries, R., Kern, J., Marick, B., Martin, R.C., Mellor, S., Schwaber, K., Sutherland, J. and Thomas, D.: 2001, Manifesto for Agile Software Development, *http://agilemanifesto.org/*, **0**, NA.

Bilal, M., Oyedele, L.O., Qadir, J., Munir, K., Ajayi, S.O., Akinade, O.O., Owolabi, H.A., Alaka, H.A. and Pasha, M.: 2016, Big Data in the construction industry: A review of present status, opportunities, and future trends, *Advanced engineering informatics*, **30**(3), 500-521.

Crawley, D., Lawrie, L., Winkelmann, F., Buhl, W., Huang, Y., Pedersen, C., Strand, R., Liesen, R., Fisher, D., Witte, M. and Glazer, J.: 2001, EnergyPlus: Creating a New-Generation Building Energy Simulation Program, *Energy and Buildings*, **33**, 319-331.

Creswell, J.W. and Poth, C.N.: 2016, *Qualitative inquiry and research design: Choosing among five approaches*, Sage publications.

Danhaive, R. and Mueller, C.: 2015, Combining parametric modeling and interactive optimization for high-performance and creative structural design, *International Association for Shell and Spatial Structures (IASS) Symposium*, **0**, 11.

Deutsch, R.: 01, *Data-Driven Design and Construction: 25 Strategies for Capturing, Analyzing and Applying Building Data*, Wiley Publishing, New Jersey, USA.

Doraiswamy, H., Ferreira, N., Lage, M., Vo, H., Wilson, L., Werner, H., Park, M. and Silva, C.: 2015, Topology-based catalogue exploration framework for identifying view-enhanced tower designs, *ACM Transactions on Graphics (TOG)*, **34**(6), 1-13.

Erhan, H., Abuzuraiq, A.M., Zarei, M., Haas, A., Alsalman, O. and Woodbury, R.: 2020, FlowUI: Combining Directly-Interactive Design Modeling with Design Analytics, *25th International Conference on Computer-Aided Architectural Design Research in Asia: Design in the Age of Humans, CAADRIA 2020*, **0**, 10.

Fu, F.: 2018, *Design and Analysis of Tall and Complex Structures*, 978-0-08-101018-1. DOI Copyright © 2018 Elsevier Ltd, ISBN.

Garg, A. and Erhan, H.: 2019, Use of Data in Design Exploration: Design Analyzer, *"Hello, Culture!" [18th International Conference, CAAD Futures 2019, Proceedings*, Korea.

Gleicher, M., Albers, D., Walker, R., Jusufi, I., Hansen, C.D. and Roberts, J.C.: 2011, Visual comparison for information visualization, *Information Visualization*, **10**(4), 289-309.

Hamilton, D.K. and Watkins, D.H.: 2008, *Evidence-based design for multiple building types*, John Wiley \& Sons.

Hanna, R.: 2012, Parametric tools in architecture: a comparative study, *Swedish Design Research Journal*, **1**, 2000-964.

Inyim, P., Rivera, J. and Zhu, Y.: 2015, Integration of Building Information Modeling and Economic and Environmental Impact Analysis to Support Sustainable Building Design, *Journal of Management in Engineering*, **31**, A4014002.

Kasik, D.J., Buxton, W. and Ferguson, D.R.: 2005, Ten CAD challenges, *IEEE Computer Graphics and Applications*, **25**(2), 81-92.

Lam, H., Bertini, E., Isenberg, P., Plaisant, C. and Carpendale, S.: 2012, Empirical studies in information visualization: Seven scenarios, *Transactions on Visualization and Computer Graphics*, **18**(9), 1520–1536.

Megahed, N.A.: 2015, Digital Realm: Parametric-enabled Paradigm in Architectural Design Process, *International Journal of Architecture, Engineering and Construction*, **4**(3), 175-184.

Roberts, A. and Marsh, A.: 2001, ECOTECT: Environmental Prediction in Architectural Education, *Architectural Information Management*, **0**, 342-347.

Sedlmair, M., Meyer, M. and Munzner, T.: 2012, Design study methodology: Reflections from the trenches and the stacks, *IEEE Transactions on Visualization and Computer Graphics*, **18**(12), 2431-2440.

Shi, X.: 2010, Performance-based and performance-driven architectural design and optimization, *Frontiers of Architecture and Civil Engineering in China*, **4**(4), 512-518.

Shneiderman, B., Fischer, G., Czerwinski, M., Resnick, M., Myers, B., Candy, L., Edmonds, E., Eisenberg, M., Giaccardi, E., Hewett, T., Jennings, P., Kules, B., Nakakoji, K., Nunamaker, J., Pausch, R., Selker, T., Sylvan, E. and Terry, M.: 2006, Creativity Support Tools: Report From a U.S. National Science Foundation Sponsored Workshop, *International Journal of Human–Computer Interaction*, **20**(2), 61-77.

Soebarto, V., Hopfe, C.J., Crawley, D. and Rawal, R.: 2015, Capturing the views of architects about building performance simulation to be used during design processes, *14th International Conference of the International Building Performance Simulation Association*, **0**, 7-9.

Terry, M. and Mynatt, E.D.: 2002, Recognizing creative needs in user interface design, *Proceedings of the 4th conference on Creativity \& cognition*, 38-44.

Thelin, C., Bunnell, S., Salmon, J. and Gorrell, S.: 2019, Difference modeling for design space exploration and comparison of three-dimensional structural simulation results, *Information Visualization*, **18**(4), 455-470.

Tory, M. and T Moller, j.C.G.: 2005, Evaluating visualizations: do expert reviews work?, *IEEE Computer Graphics and Applications*, **25**(5), 8-11.

Touloupaki, E. and Theodosiou, T.: 2017, Performance Simulation Integrated in Parametric 3D Modeling as a Method for Early Stage Design Optimization—A Review, *Energies*, **2017**(10), 637.

Vergara, M.: 2018, Big data in building design: A review, *Electronic Journal of Information*

Technology in Construction, **23**, 259-284.
Wang, W. and Steenblik, R.S.: 2019, Bespoke Tools Providing Solutions for Contemporary Problems-Novel BIM practice for architects, *Proceedings of the 24th CAADRIA Conference*, **2**, 111-120.
Weytjens, L., Attia, S., Verbeeck, G. and Herde, A.: 2012, The 'Architect-friendliness' Of Six Building Performance Simulation Tools: A Comparative Study, *International Journal of Sustainable Building Technology and Urban Development*, **10**(5390), 237-244.
Woodbury, R. 2017, The Grammar Lens: How Spatial Grammar Channels Interface Design, *in* J.H. Lee (ed.), *Morphological Analysis of Cultural DNA: Tools for Decoding Culture-Embedded Forms*, Springer Singapore, Singapore, 199-226.
Zapata-Lancaster, G. and Tweed, C.: 2016, Tools for low-energy building design: an exploratory study of the design process in action, *Architectural Engineering and Design Management*, **12**(4), 279-295.
Abu Zuraiq, A.: 2020, *DesignSense: A Visual Analytics Interface for Navigating Generated Design Spaces*, Master's Thesis, Communication, Art \& Technology: School of Interactive Arts and Technology.